Hydraulics, Coastal Systems and Sustainment Engineering

Advanced Concept ARO 2001 Centrifuge Workshop

January 31 - February 1, 2001

US Army Engineer Research and Development Center

Vicksburg, Mississippi, USA

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C-CORE, St. John's, Newfoundland, Canada

TOPICS OF INTEREST

- **Sustainment engineering**
  - **semi-permanent or permanent military structures**
- **Landing over the shore (LOTS)**
- **Offshore disposal; dredge material disposal; military cleanup**
- **Beach/shore erosion**
- **Landing craft and shore behavior**
- **Offshore platform foundations**
- **Offshore pipelines/cables**
- **Navigation and flood control**

EXAMPLE PROJECTS

1. Wave induced seabed liquefaction

- Hydraulics & Beach/shore erosion

2. Ice / structure interaction

- Hydraulics

3. Ice gouge / pipeline interaction

- Offshore pipelines/cables (& Landing craft and shore behavior)

4. Confederation Bridge

- Offshore platform foundations

5. Spudcan foundation removal

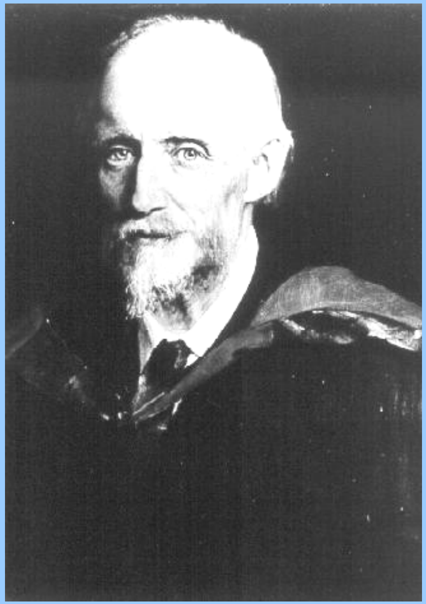
- Sustainment engineering & Offshore platform foundations

6. Drag anchor performance

- Sustainment engineering & Offshore platform foundations

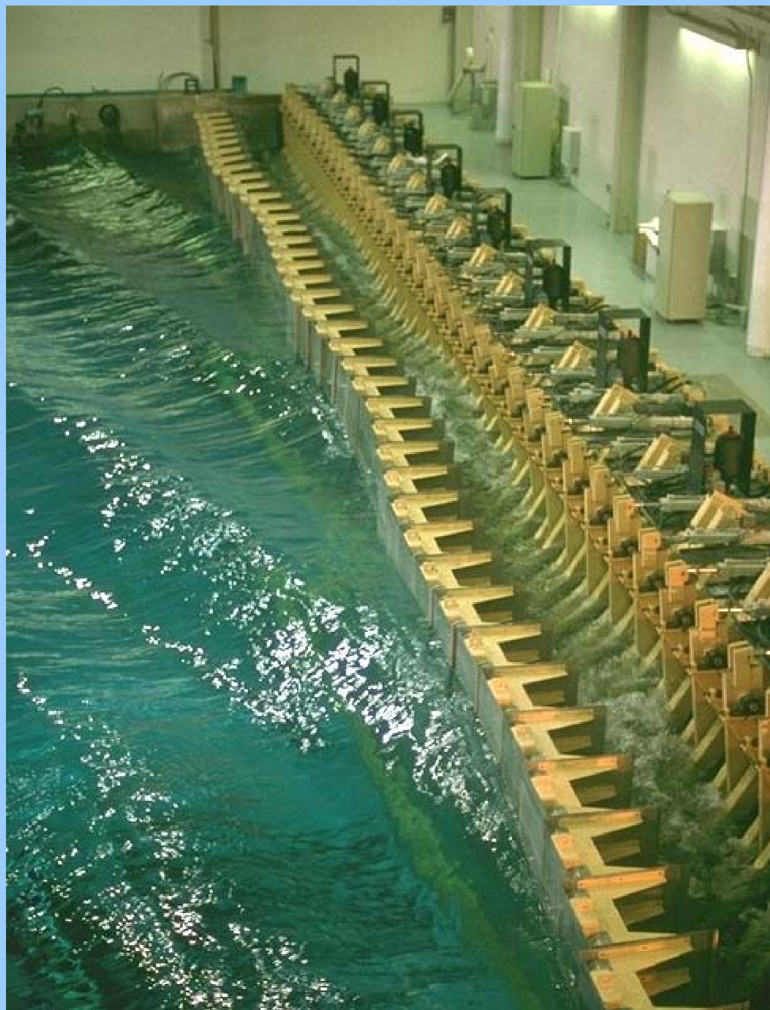
Centrifuge Modelling for Hydraulics

- **Hydraulic modelling similitude**
  - **Re, $Fr = V / \sqrt{gL}$, We ratios, etc**
- **Centrifuge permits g as a variable**
  - **limited range of geometric scale factors**
  - **similarity of several ratios simultaneously**
  - **hydraulic/soil interactions**
- **Scaling laws derived, eg Goodings (1984)**
  - **laminar seepage, turbulent surface flow, erosion, and rate of sediment transport**
  - **eg Erosion of cohesionless soil modelled if all soil particles are reduced in size by the factor N.**
- **Embankment overtoppings**
- **River bank failure due to seepage**
- **Modelling of transient unsaturated flow is valid**
- **Water-wave submerged causeway interaction**



Osbourne Reynolds

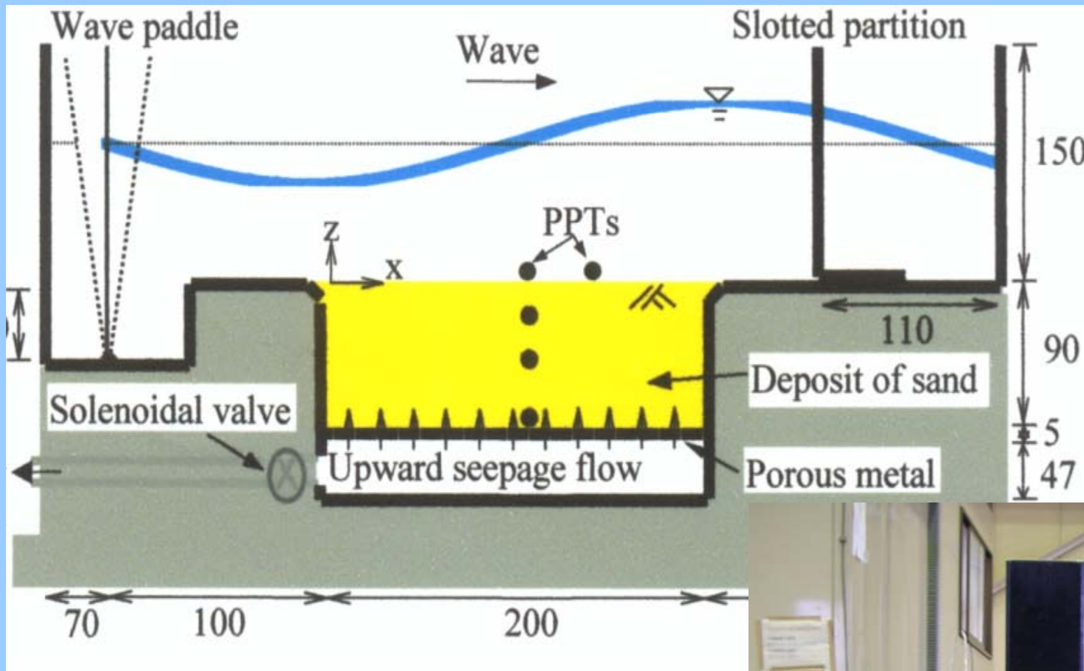
Wave Induced Seabed Liquefaction



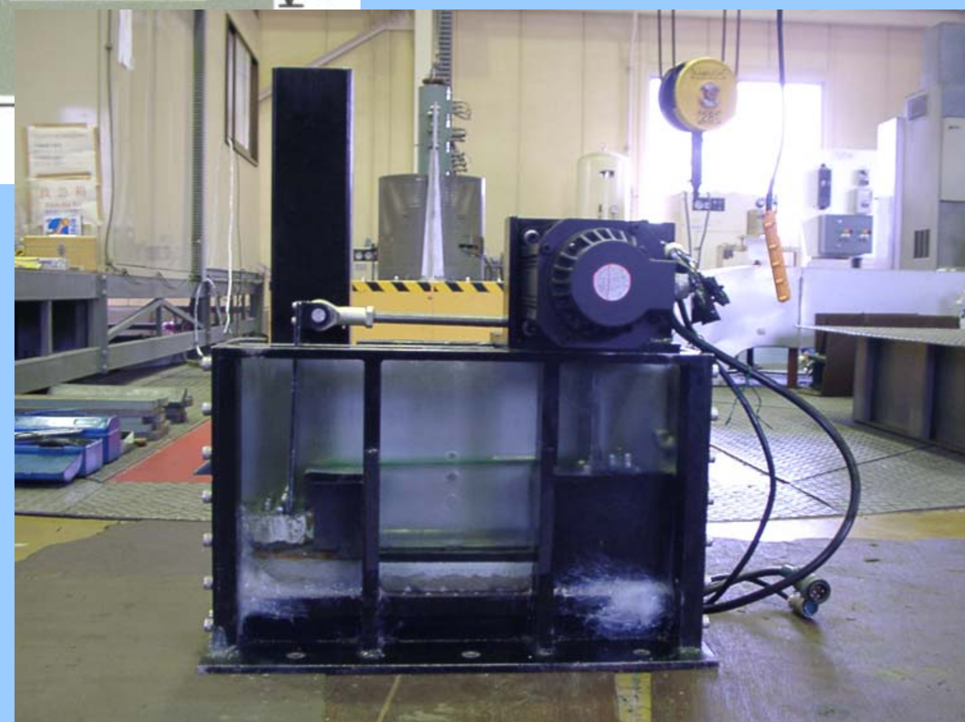
Physical Model Test in OTRC Wave Basin, Houston

- **Wave modelling in drum**
  - **Transient & theory**
  - **Wave trains**
  - **Causeway interaction**
  - **Sekiguchi & Phillips (1992)**
- **Wave - seabed interaction**
  - **liquefaction studies**

Wave Induced Seabed Liquefaction

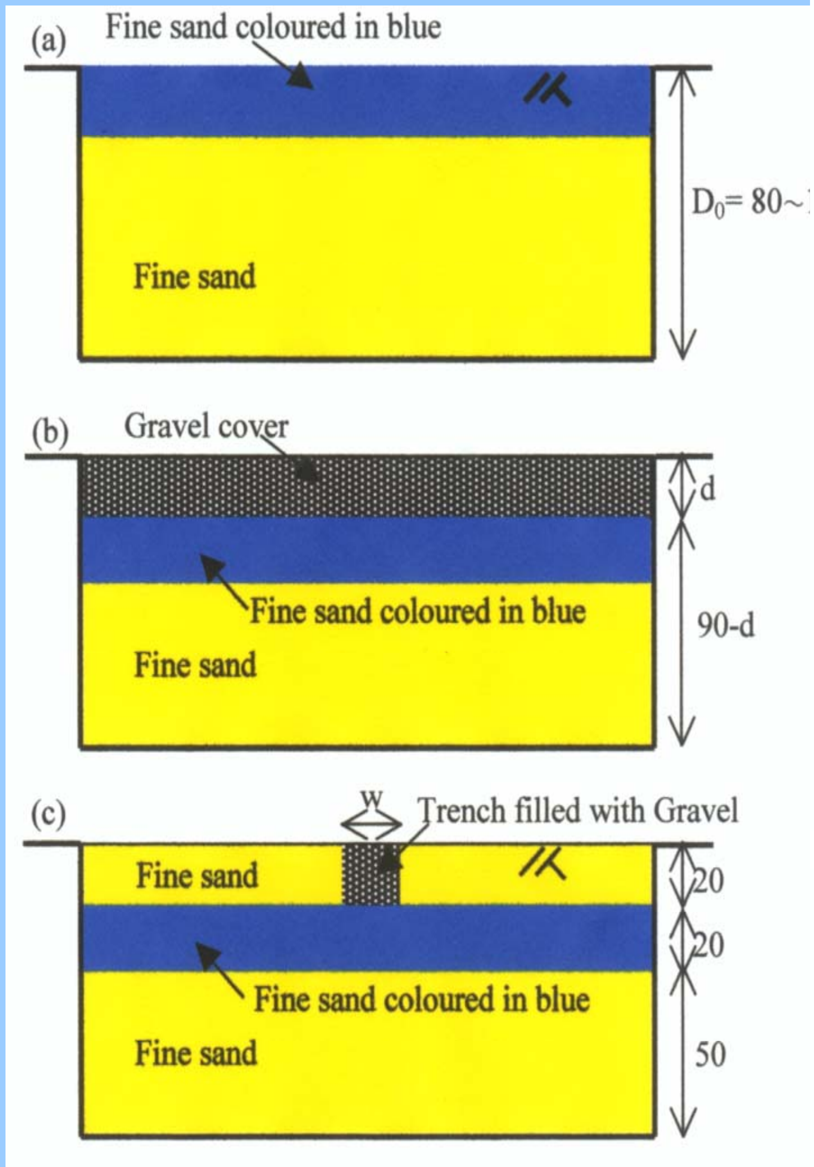


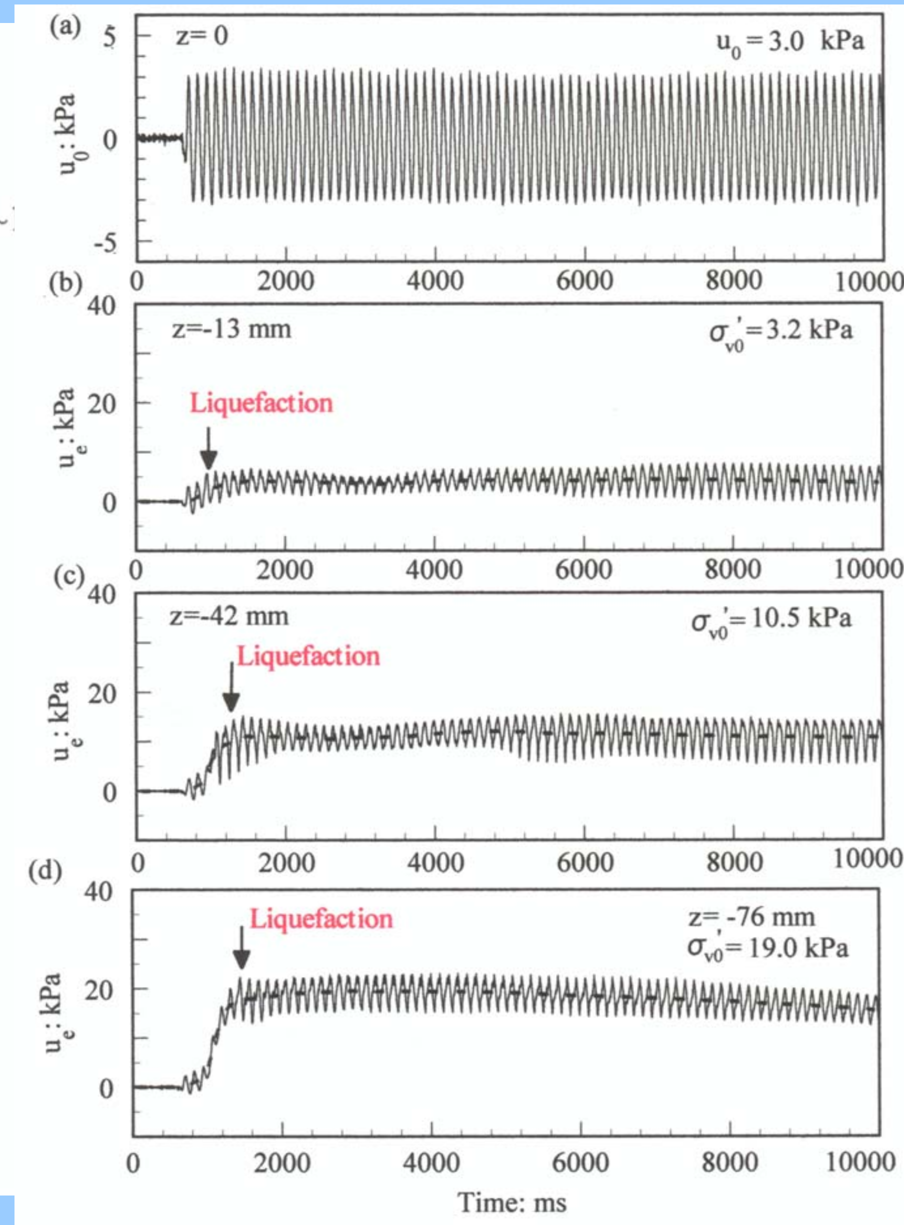
- **50g tests**
  - **4m water depth**
  - **4.5m fine sand**
- **Sekiguchi et al (2000)**



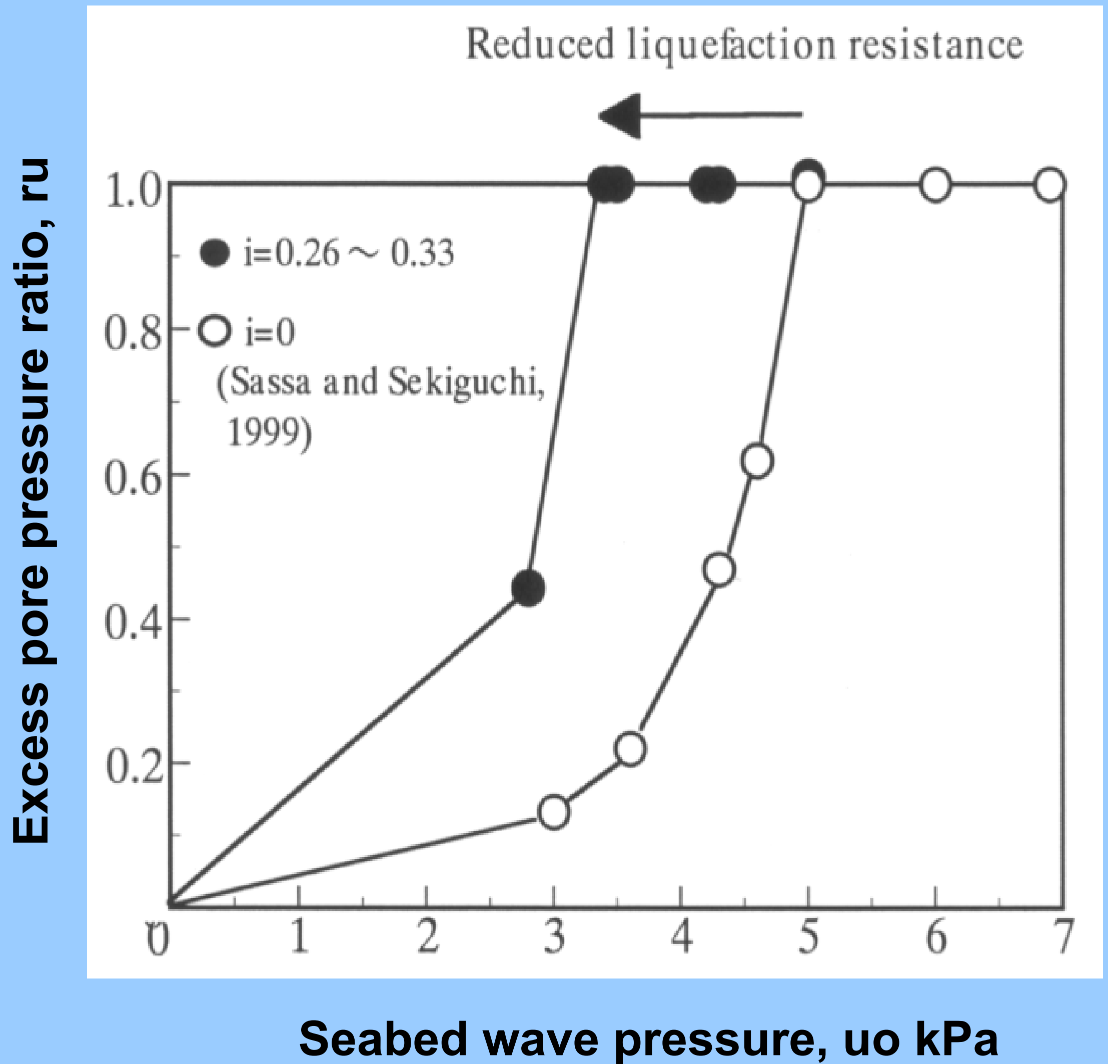
- **Viscous pore fluid**
  - **simultaneous time scaling of**
  - **consolidation &**
  - **inertia**

Wave Induced Seabed Liquefaction





Wave Induced Seabed Liquefaction

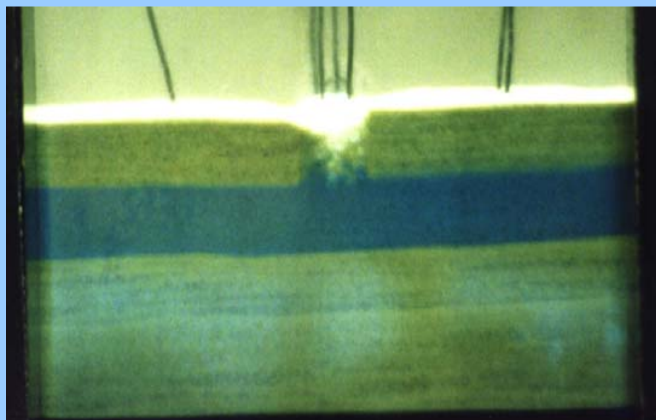


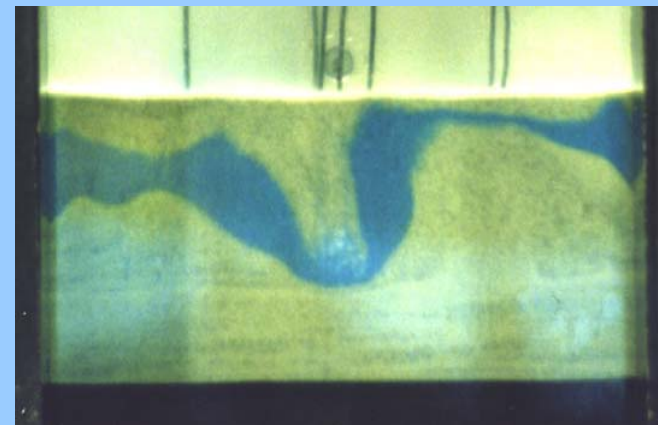
Wave Induced Seabed Liquefaction

Photographs of Gravel Trench, Test SK16

Before wave loading

After wave loading

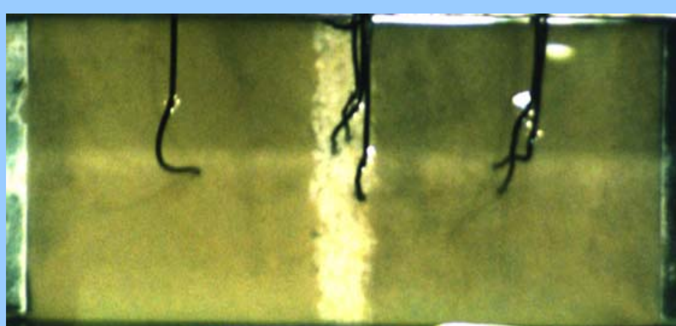


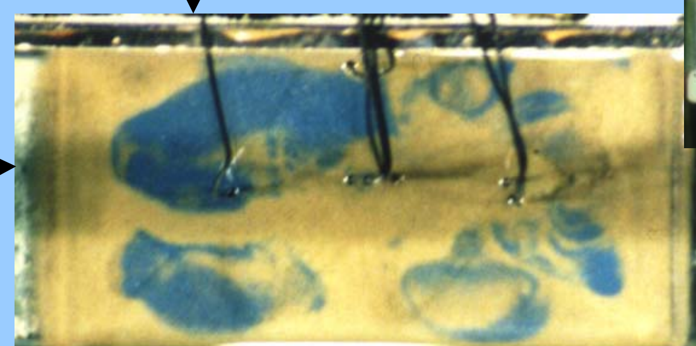


Elevation view

Cross section through line A-A'

A





A'

Plan view

Ice / structure interaction

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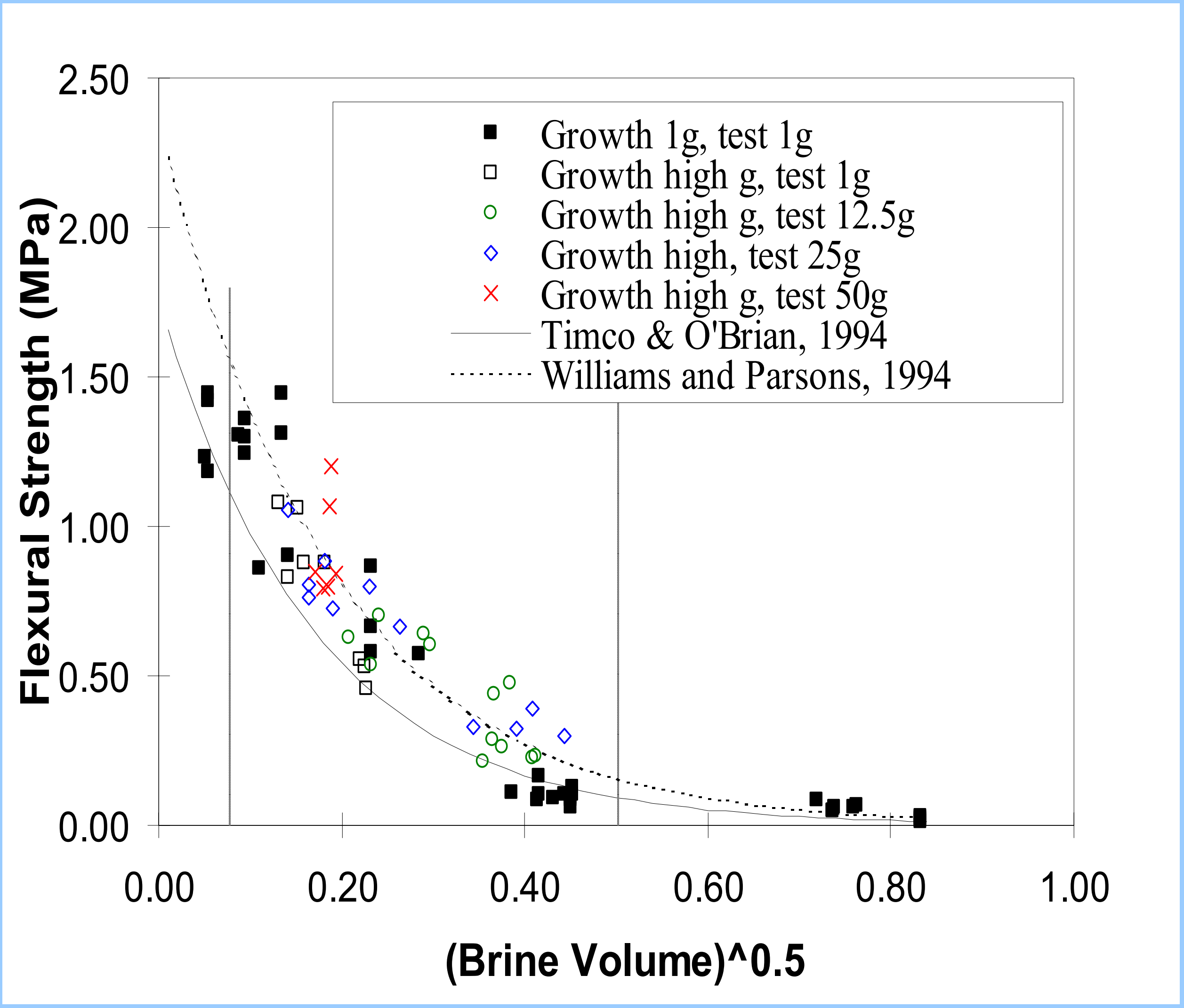
- Centrifuge Models Complement Ice Tank Tests
  - Level ice - freshwater & saline
  - Rubble fields
  - Unconsolidated rubble keels
  - Barrette et al (2000)

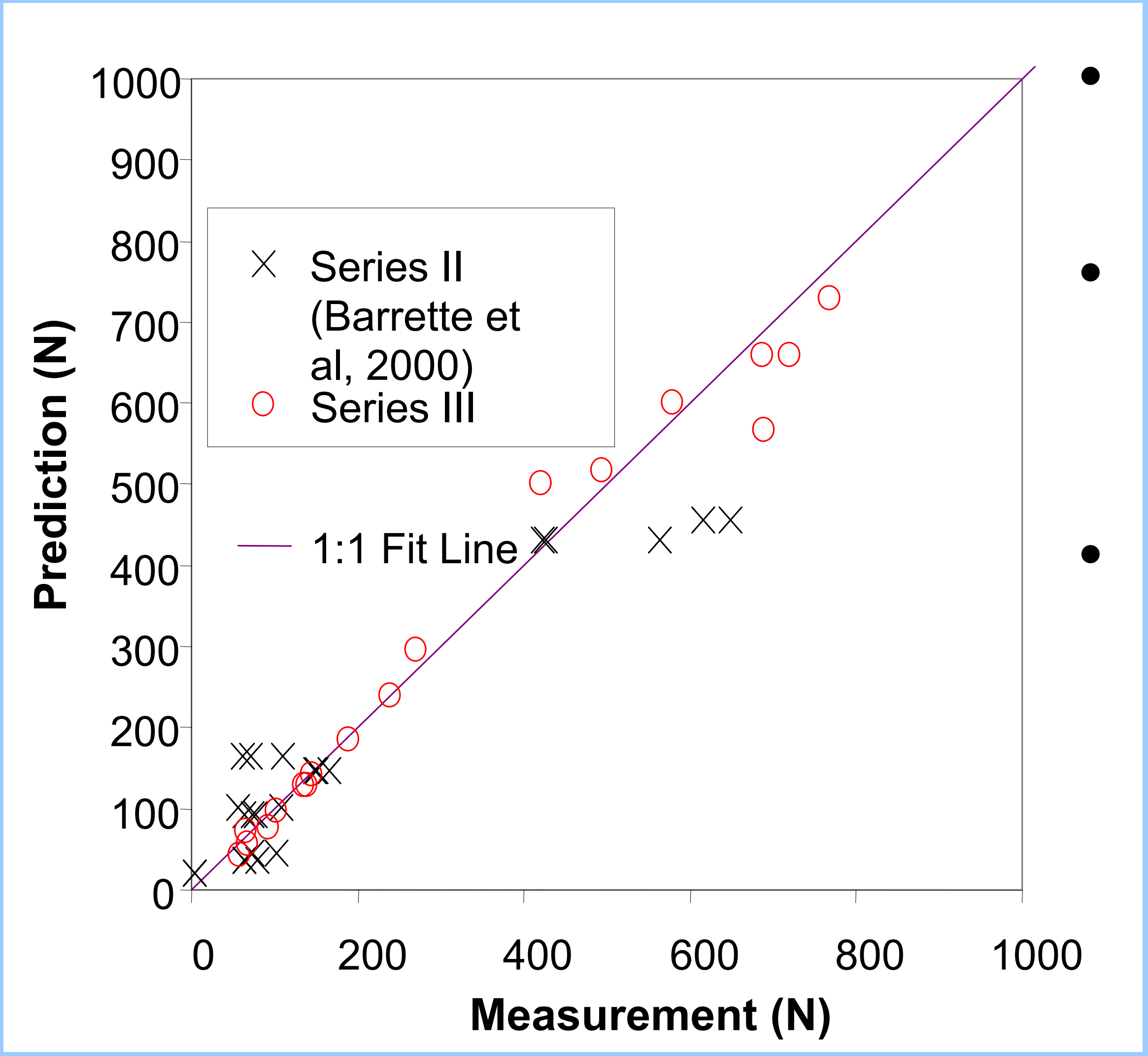
Scaling Considerations

- **Froude number, $F^2 = V^2 / gL$**
- **Cauchy number, $C^2 = V^2 \rho / E$**
  - **Reduced scale model at 1g**
    - **Model flexural strength reduced by scale factor**
    - **Use of doped ice, not real material**
  - **Reduced scale model at ng**
    - **Model flexural strength same as prototype**
    - **Use of real material**
    - **Assumes classical centrifuge model scaling**
    - **what if fracture mechanics is dominant?**

Flexural Strength Comparison

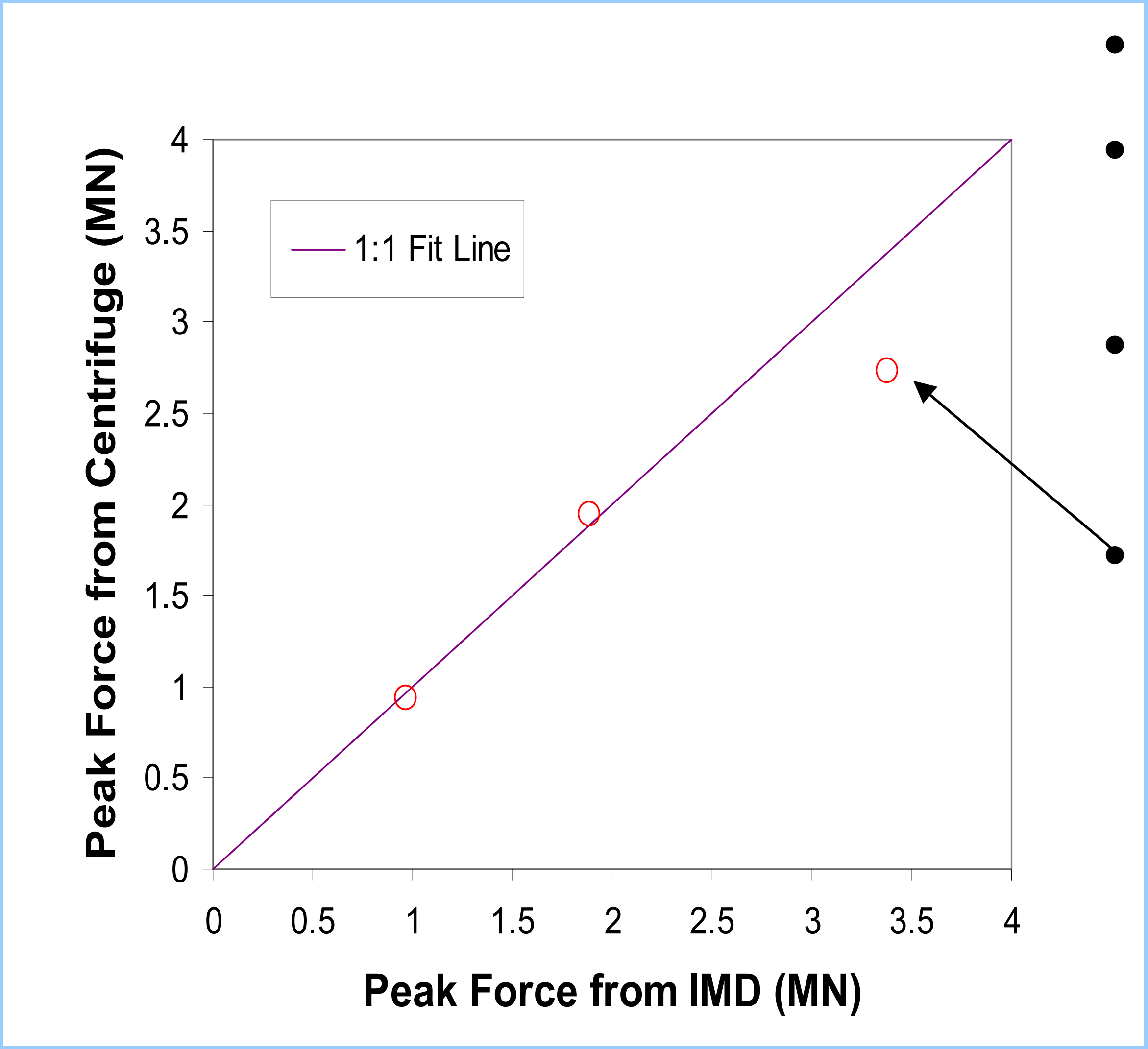


Horizontal Load Comparison



- **Centrifuge models**
- **Level ice models**
  - **Freshwater**
  - **Saline**
- **Prediction from Lau (1999)**

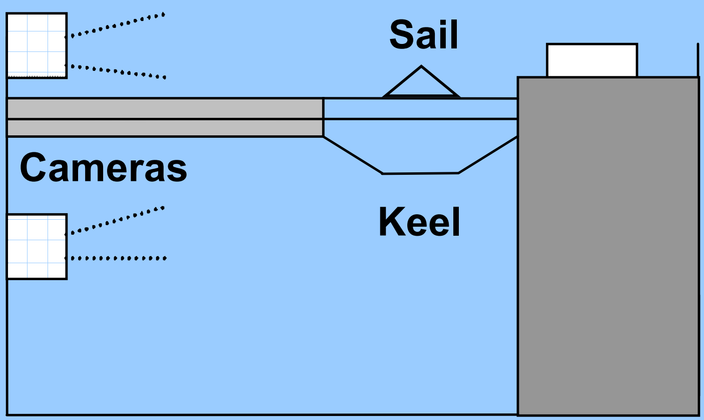
Modelling of Models Comparison

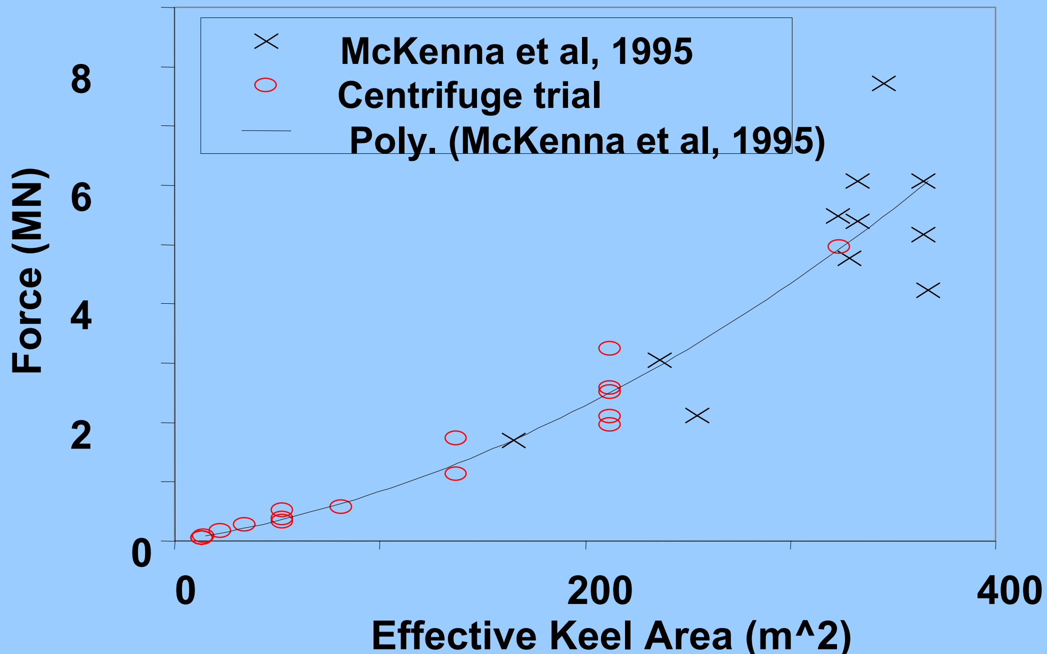


- **Level ice models**
- **Centrifuge models**
- **Ice Tank Tests**
- **Shear dominant**
  - **lower D/t**

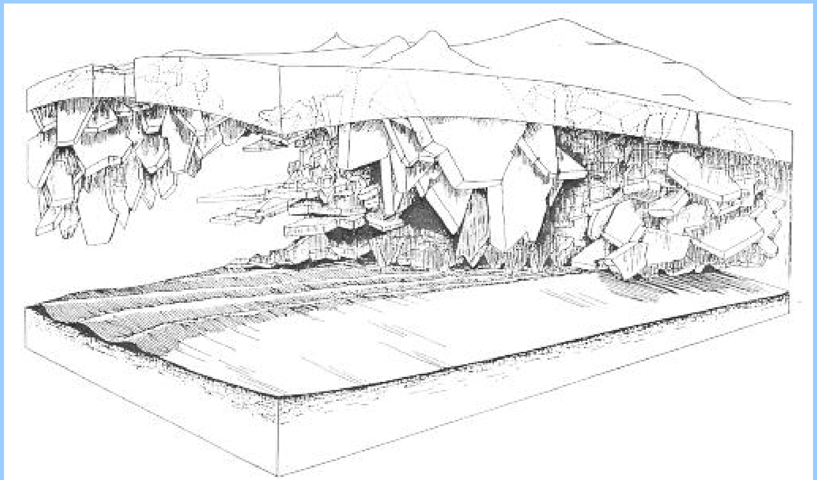
Rubble Keel Load Comparison

- Structure width 5 and 10 m
- Keel depth up to 11 m deep
- Keel width up to 50 mm wide
- Ice Tank & Centrifuge Tests





Ice gouge / pipeline interaction



PRESSURE RIDGE ICE SCOUR EXPERIMENT

'To develop the capability to design pipelines and other seabed installations in regions scoured by ice, taking into account the soil deformations and stress changes which may be caused during a scour event'.

Ice gouge / pipeline interaction

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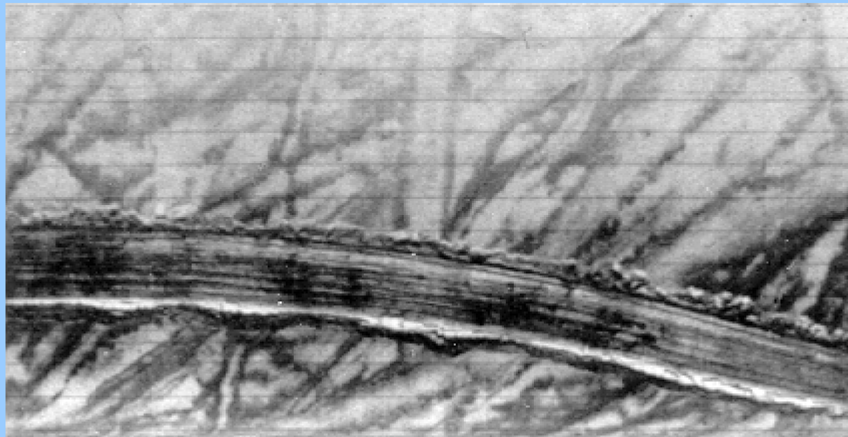

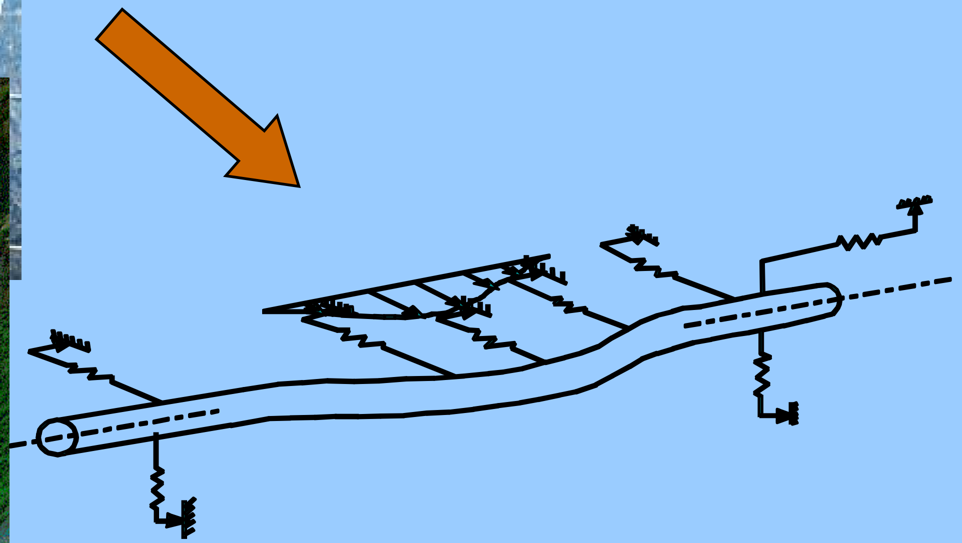

Ice gouge / pipeline interaction

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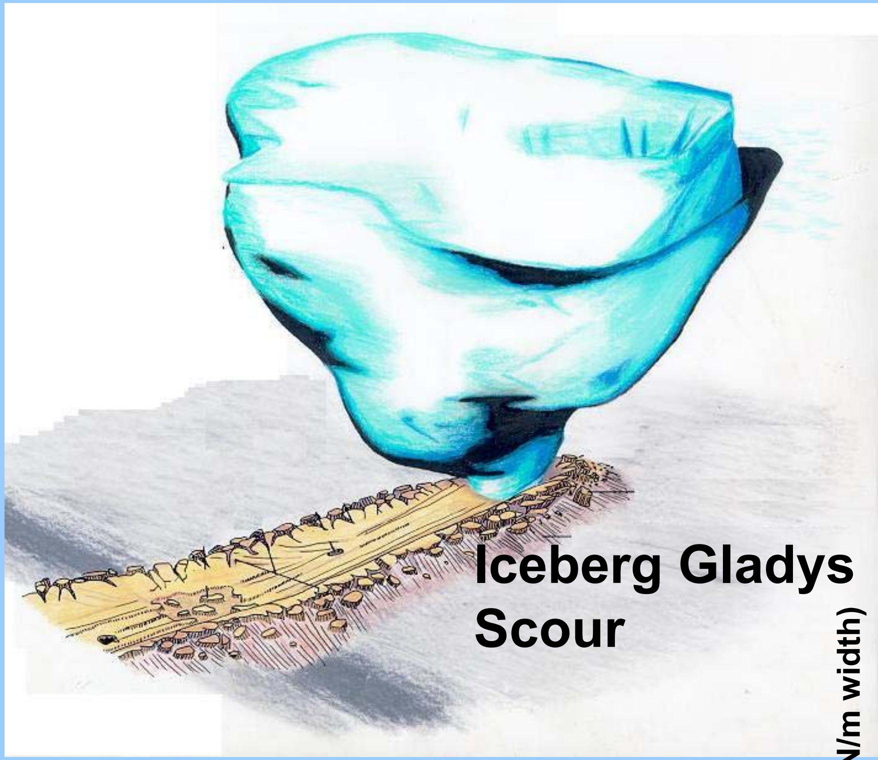
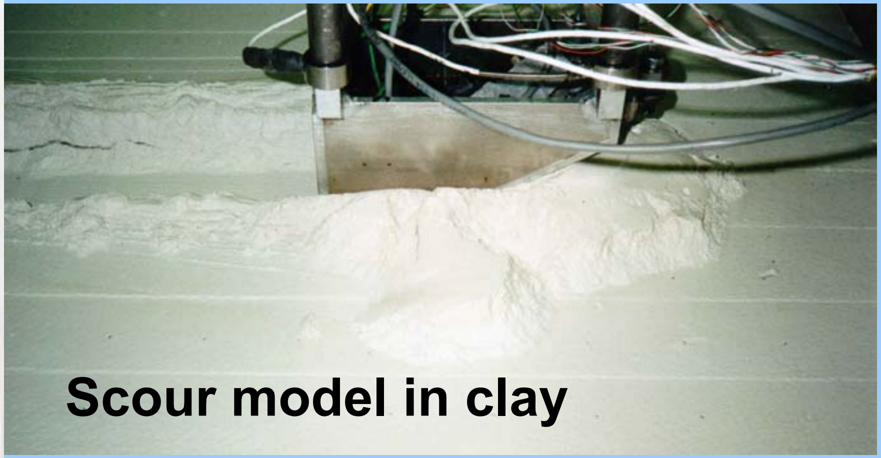
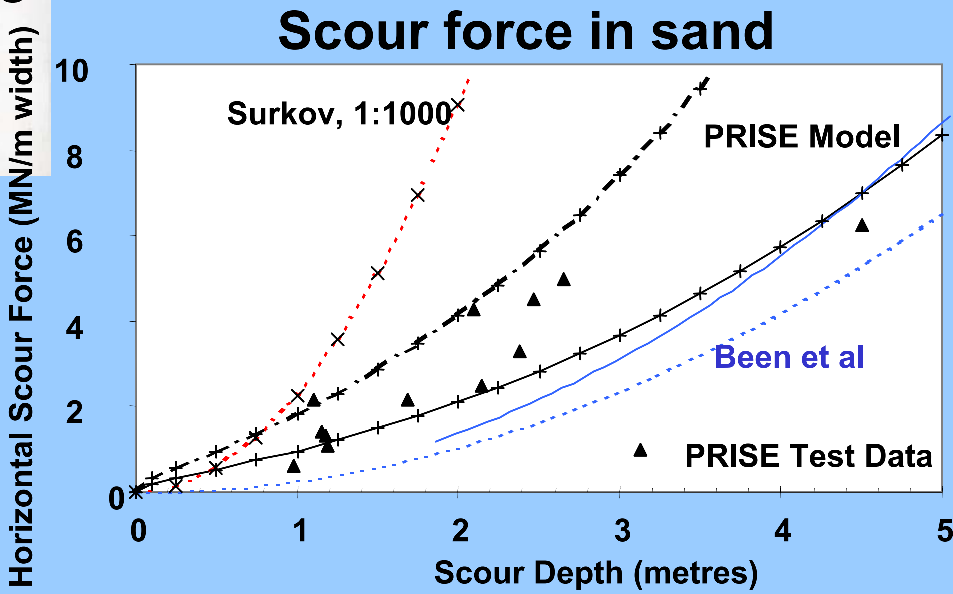


Iceberg Gladys Scour

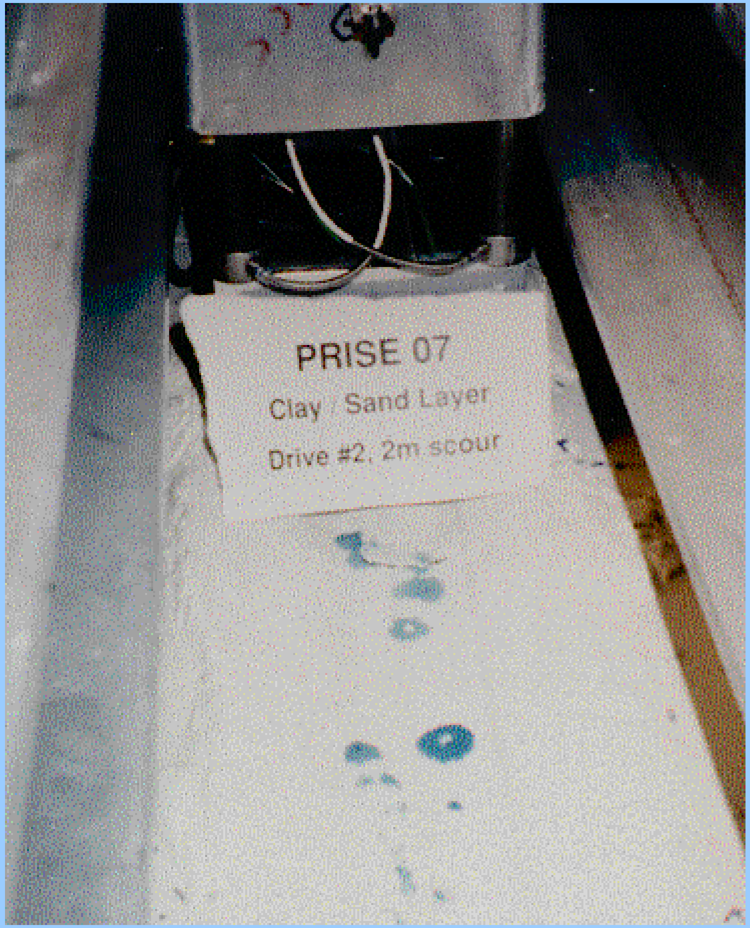




Woodworth-Lynas, et al (1996)

Ice gouge / pipeline interaction

Sand boils in scour path?



Ice gouge / pipeline interaction

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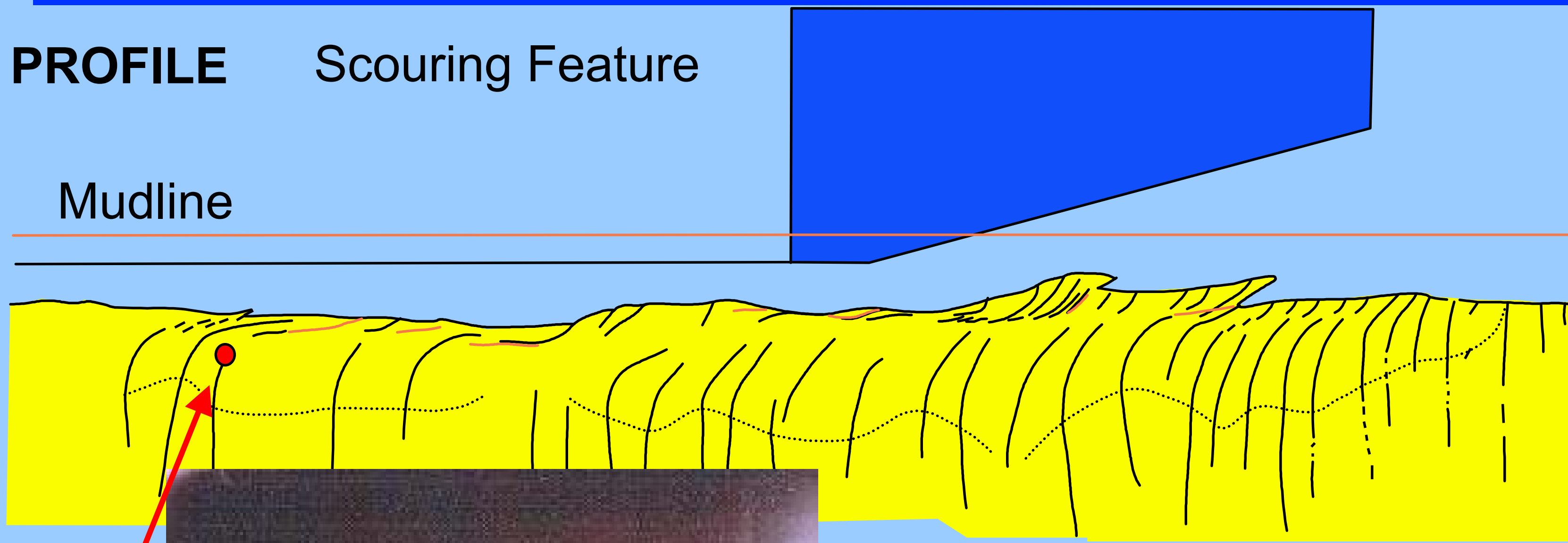

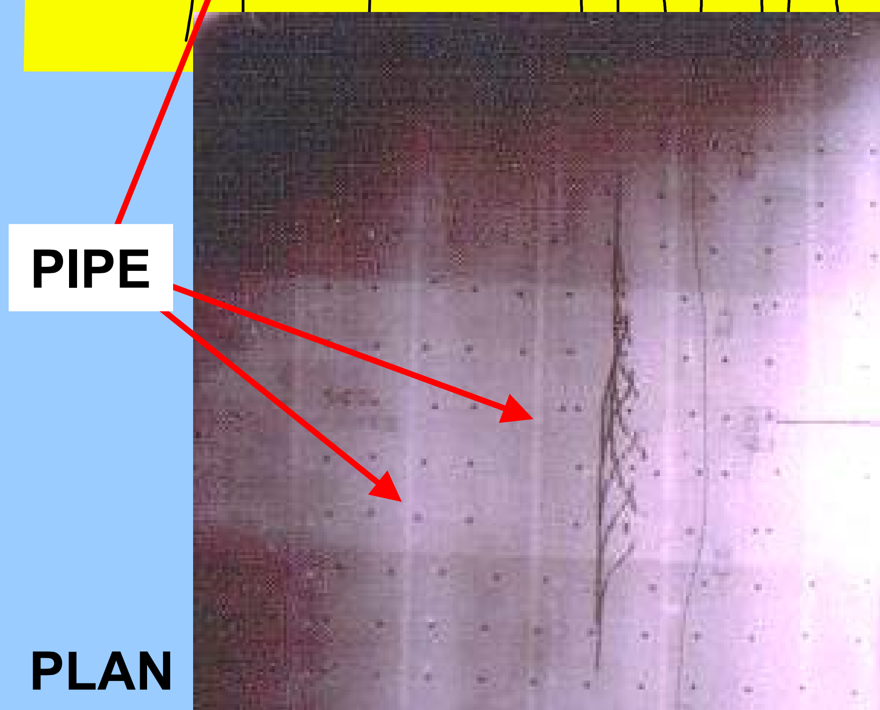

DESIGN GUIDELINES:
- **SCOUR FORCES**
- **DEFORMATION FIELDS**

- **PIPE RESPONSE**
- **ENGINEERING MODEL**

Confederation Bridge

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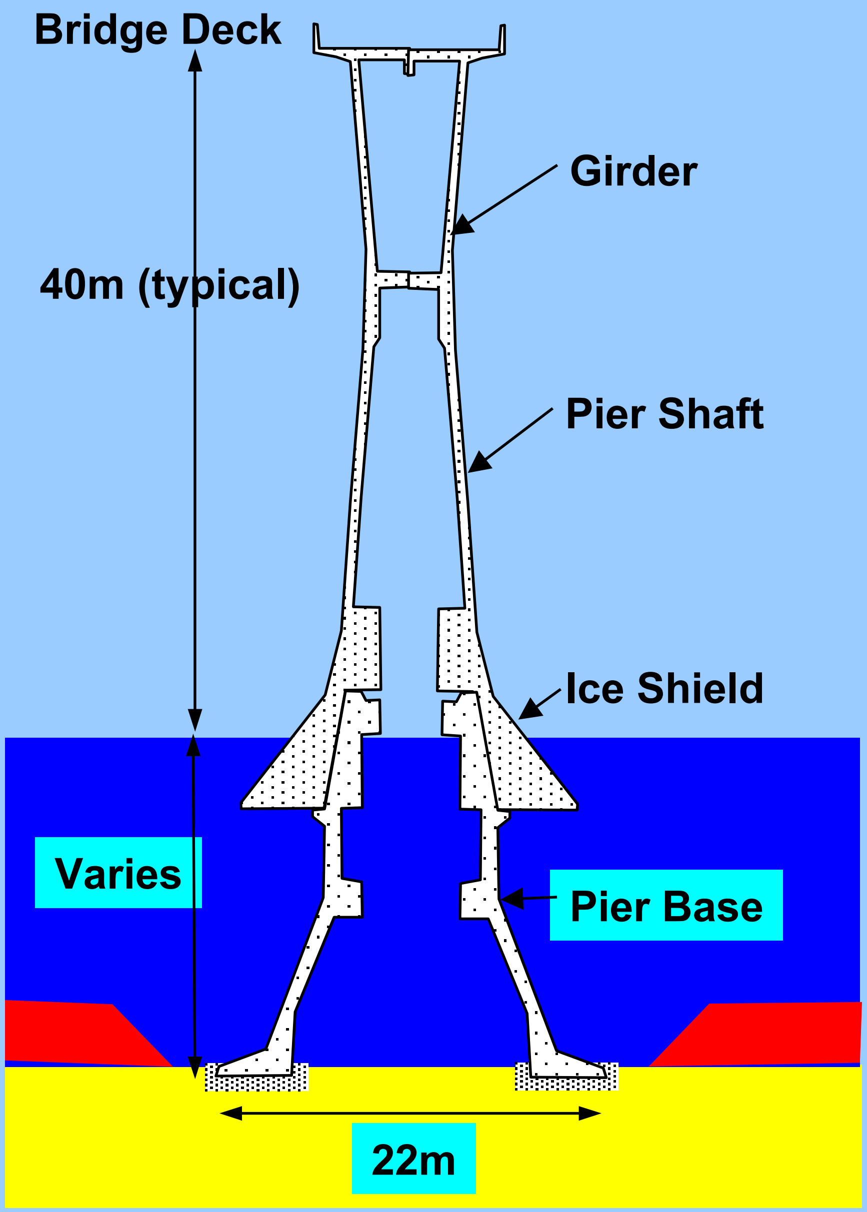
Overview

Confederation Bridge



CROSS-SECTION OF TYPICAL BRIDGE PIER

Over 60 piers.

Dredge to foundation level.

Place ring foundation.

Pour tremie pad.

Limit State Design Approach

In preliminary design, 12 pier designs were not acceptable.

Need to understand how pier foundations would behave.

Kosar et al (1999)

Confederation Bridge

Confederation Bridge

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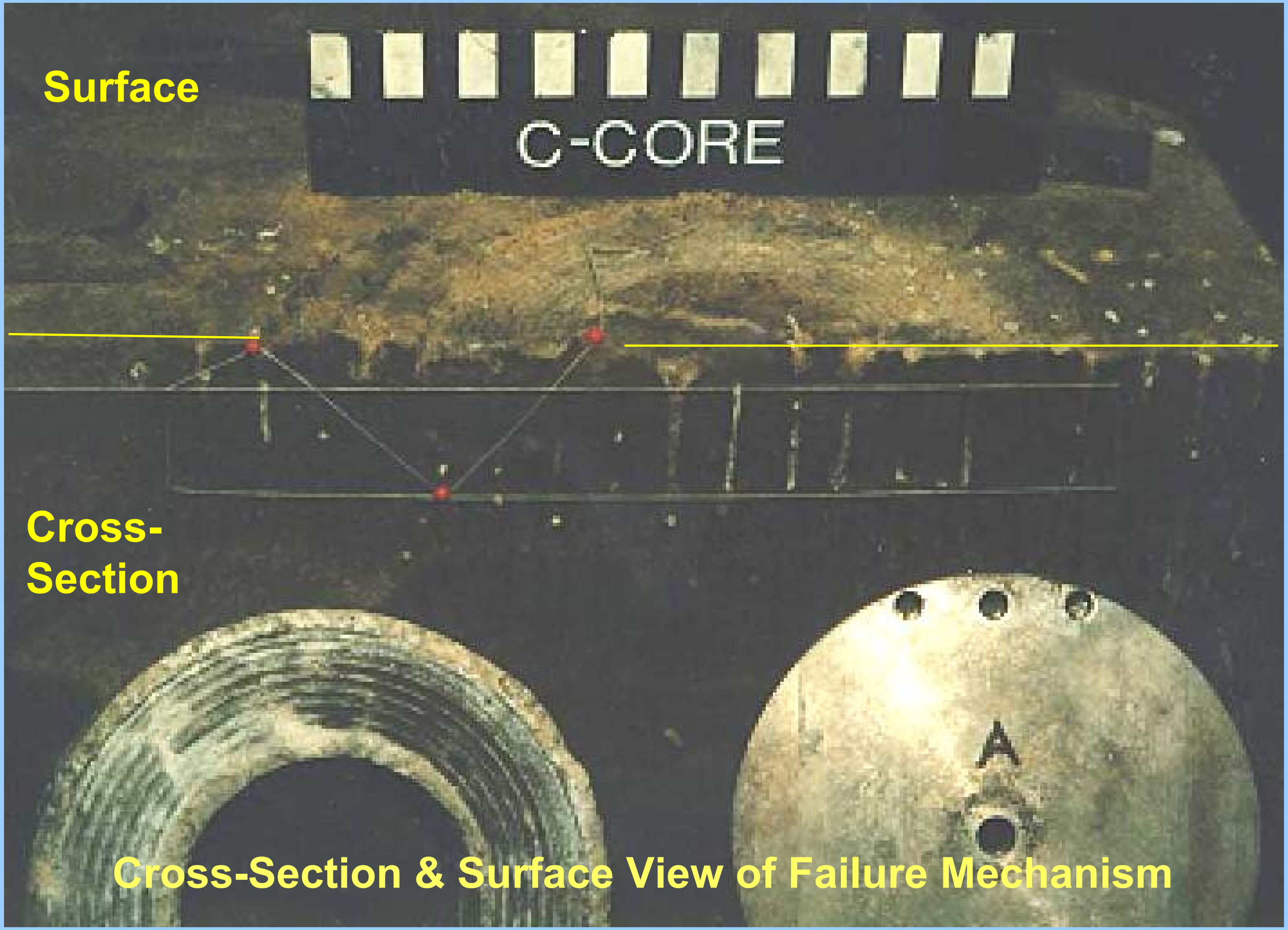
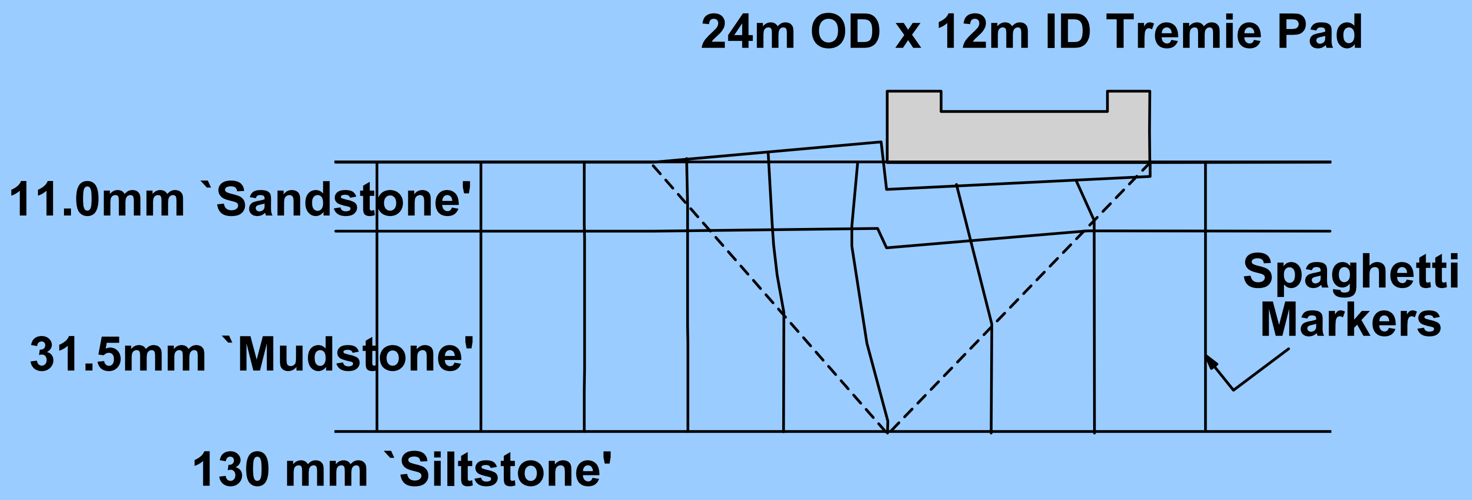
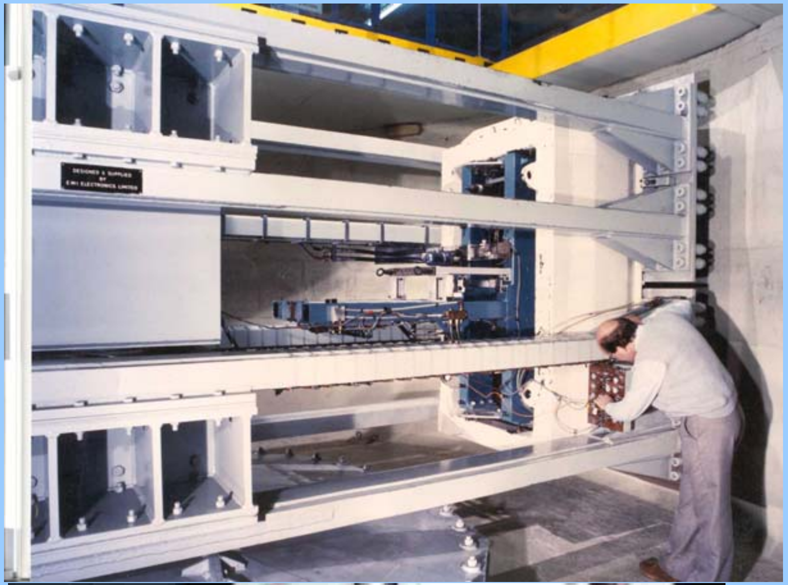


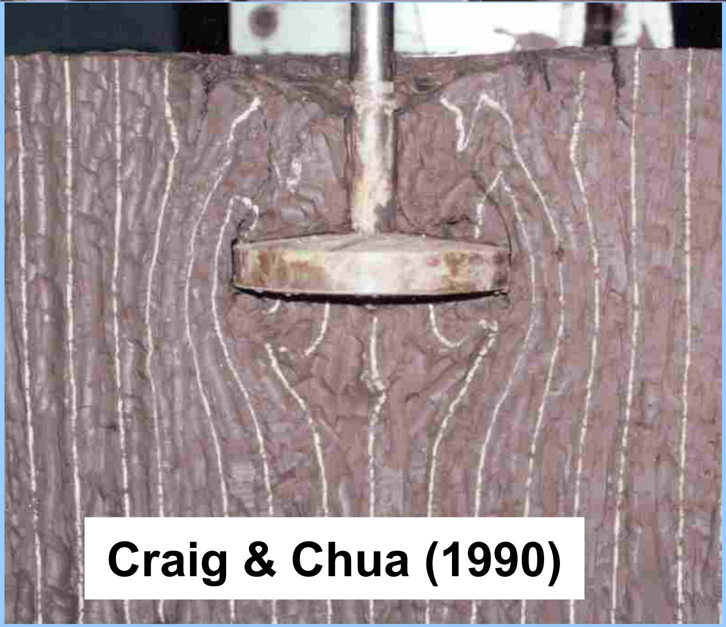
Confederation Bridge



		Bearing Capacity MPa
Centrifuge Test		1.69
2 Part Wedge	Original	1.52
	Modified	1.74
2D Limit Equilibrium		1.73
3D Limit Equilibrium		1.63

Spudcan foundation removal

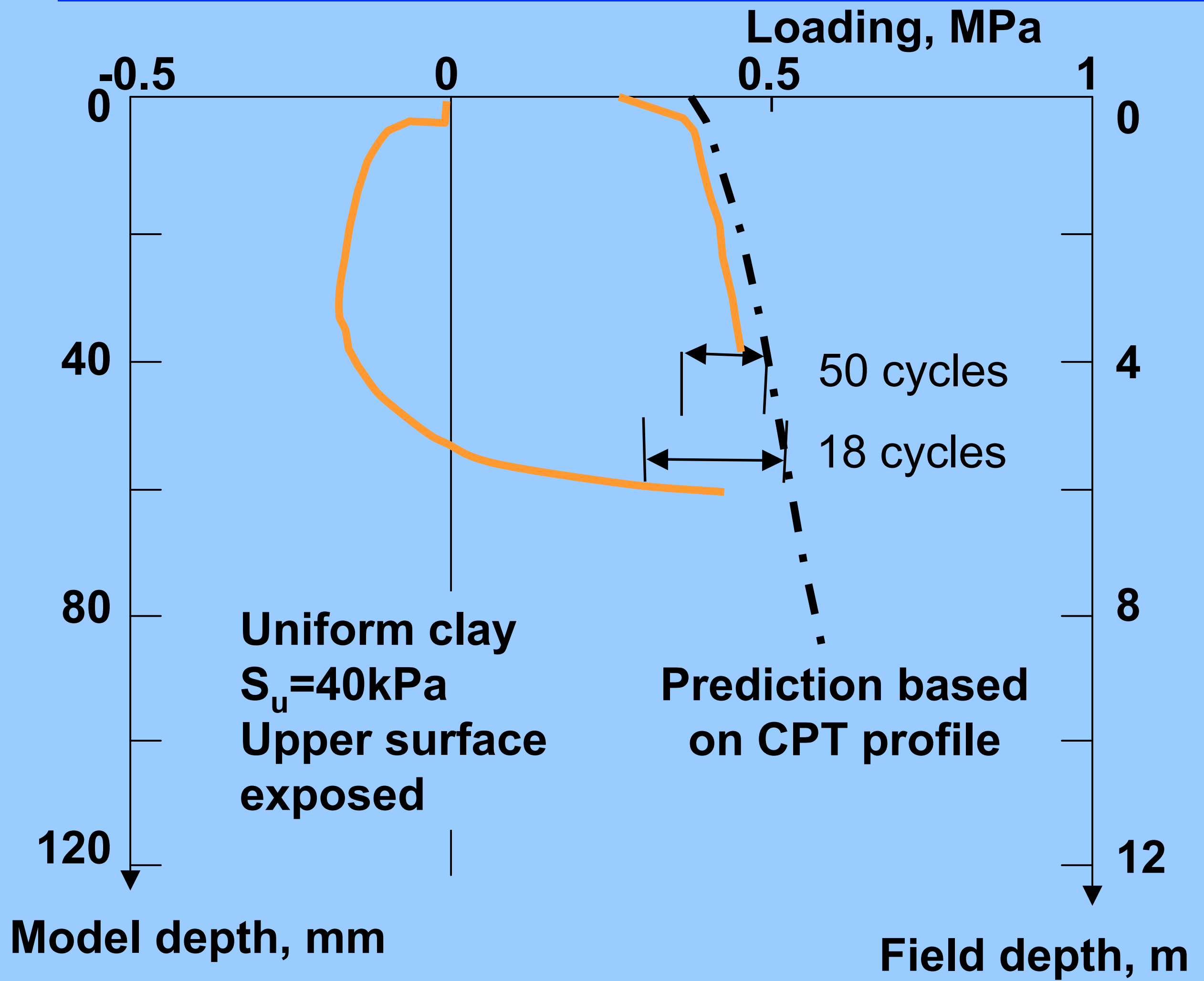




Craig & Chua (1990)

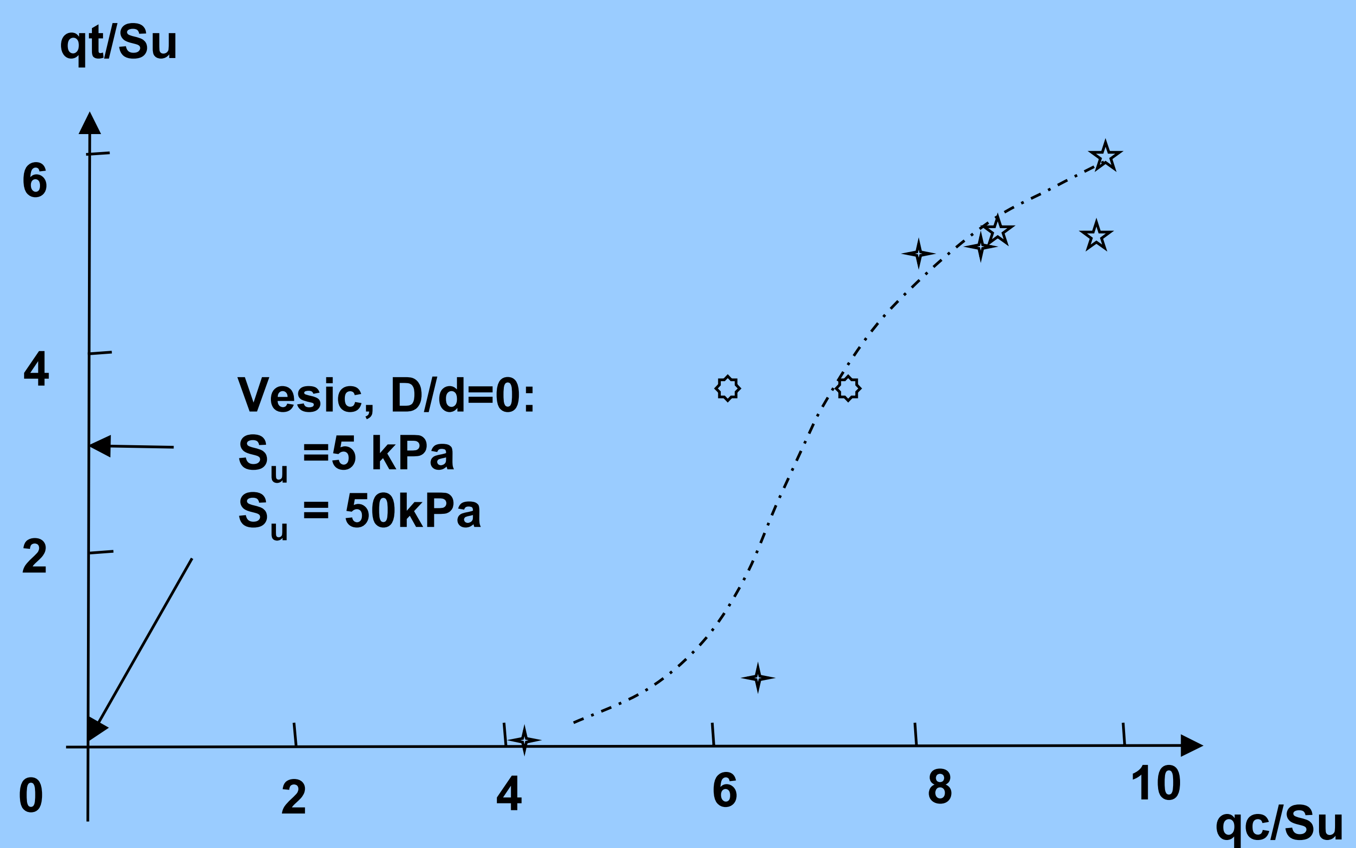
Spudcan foundation removal

University of Manchester



Monotonic Installation, limited cyclic loading and undrained breakout

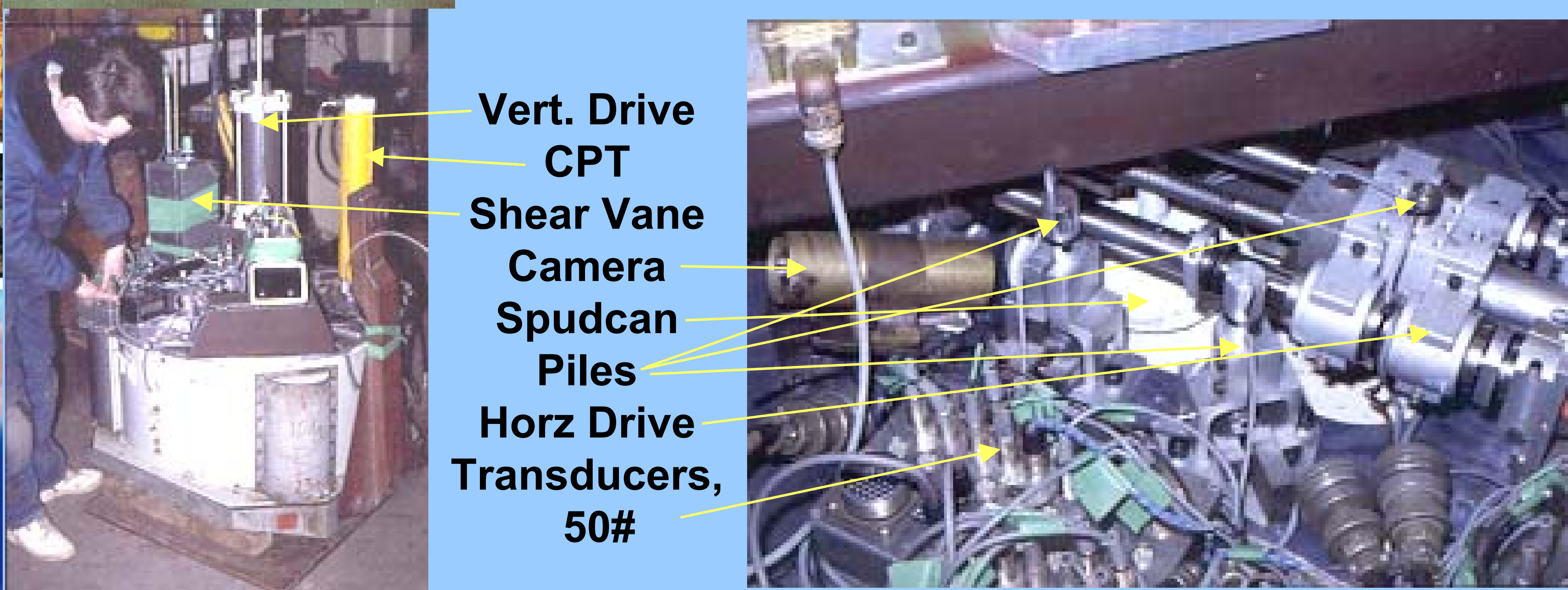
Spudcan foundation removal



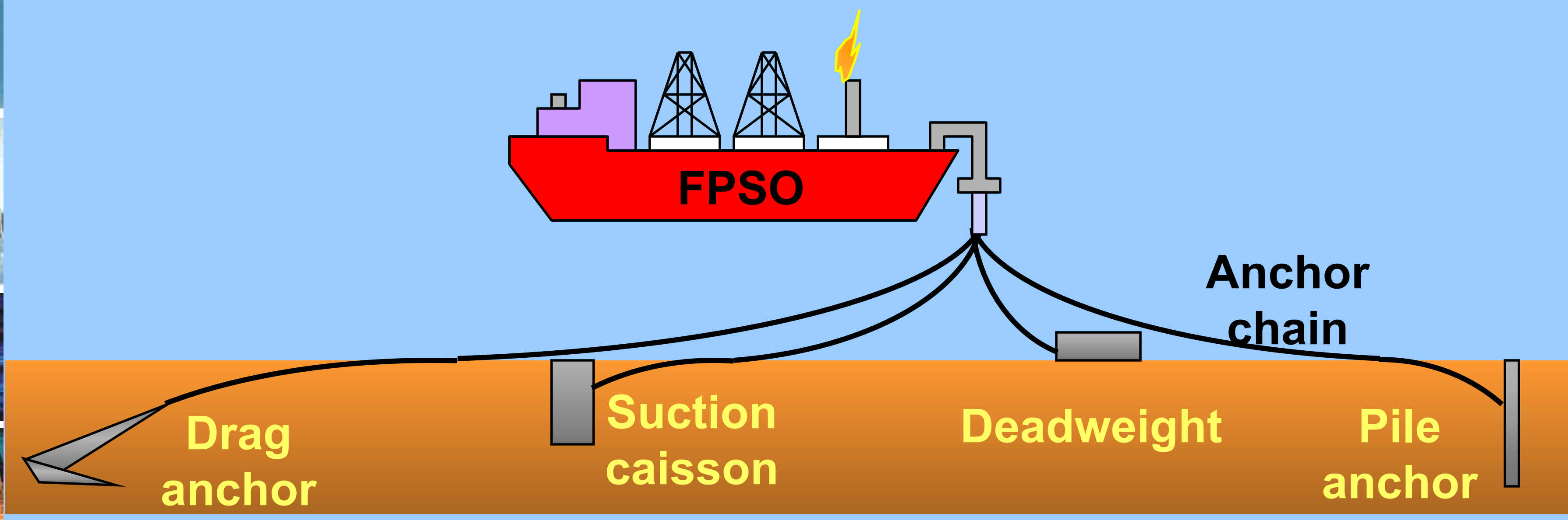
Relationship between Installation and breakout stresses for D/d <0.5

Spudcan foundation removal

- **Methods to reduce uplift resistance**
- **Spudcan / Pile Interaction**
  - Craig (1998)
  - Siciliano et al (1990)

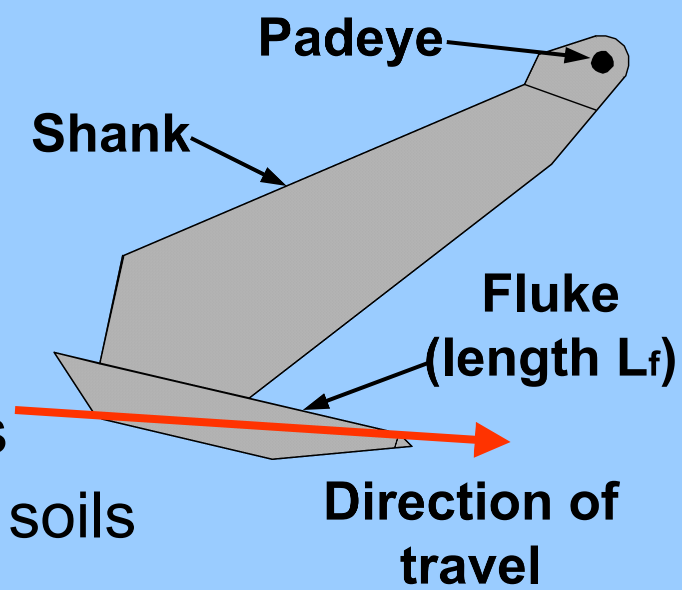


Drag anchor performance



- High holding capacity (efficiency)
- Relatively easy to install
- Retrievable & reusable

- Design methods largely empirical
- Unsuitable in hard /rocky seabeds
- Uncertain performance in layered soils



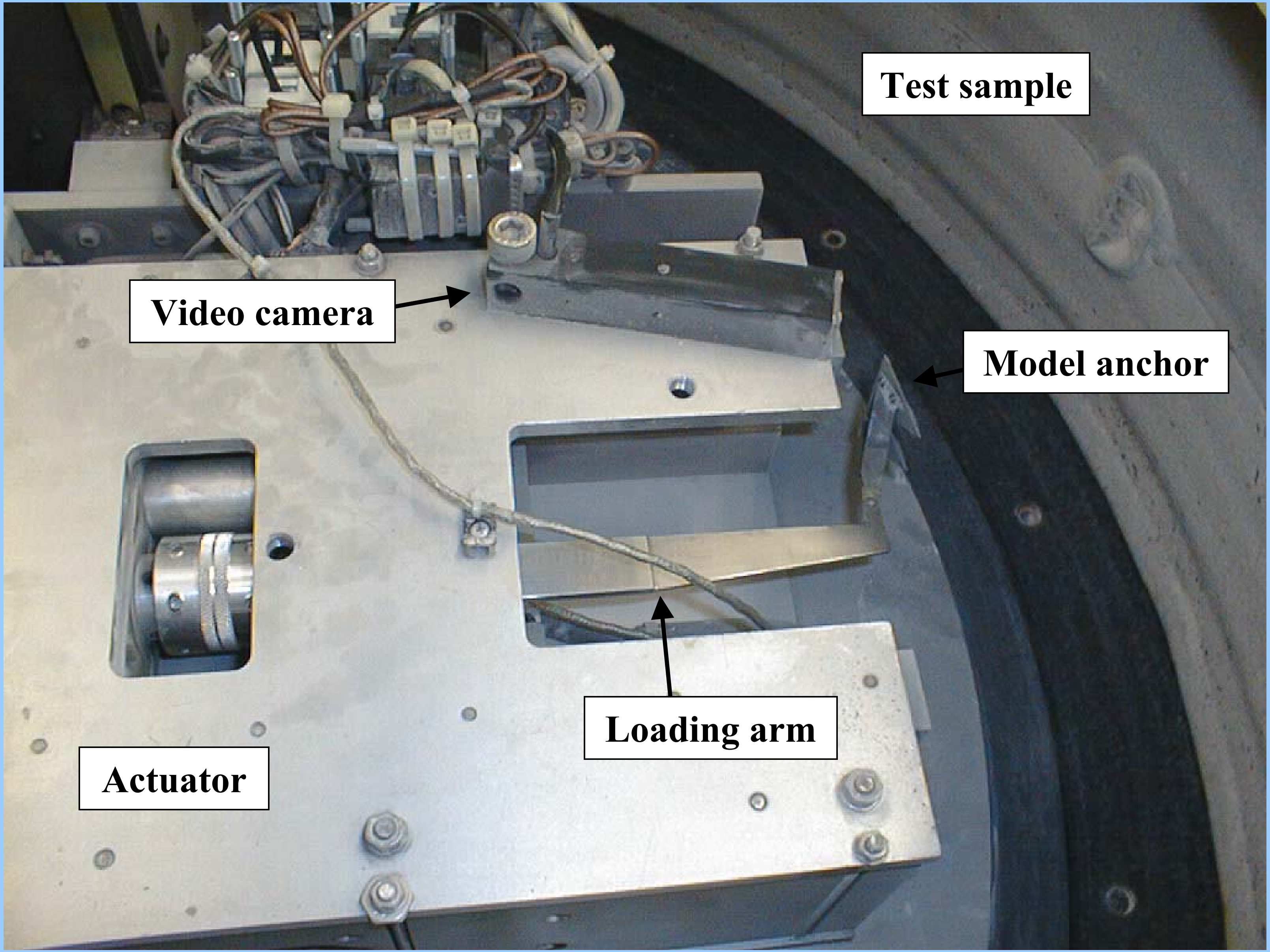
Drag anchor performance

1:160 scale model of 32 tonne Vryhof Stevpris

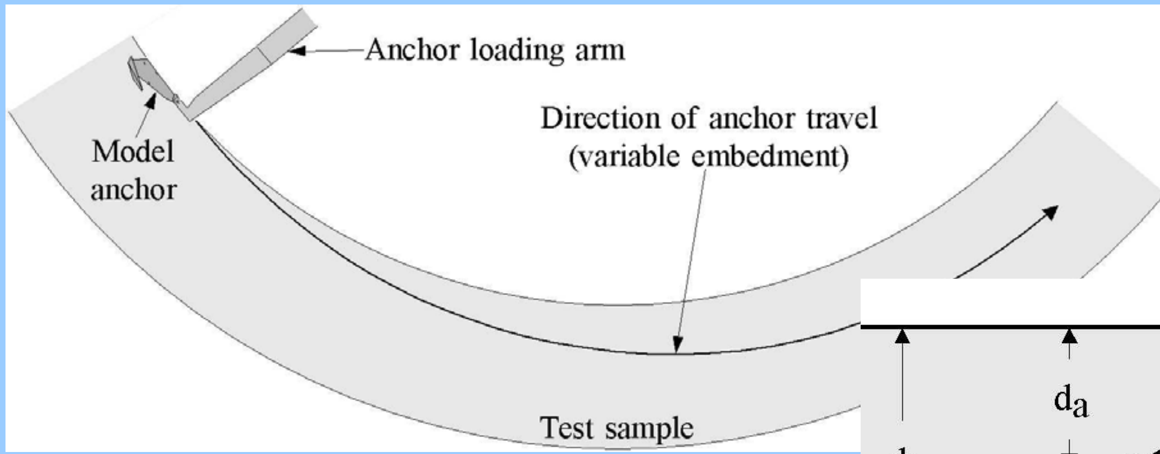
Fluke length: 31 mm (5 m prototype)

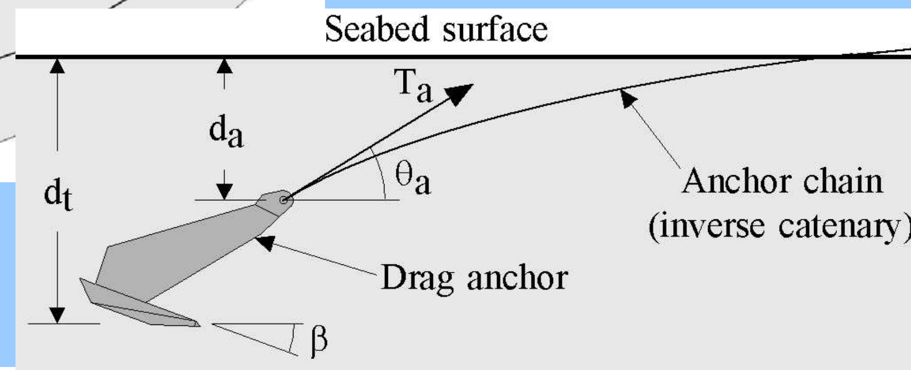
O'Neill et al (1999)

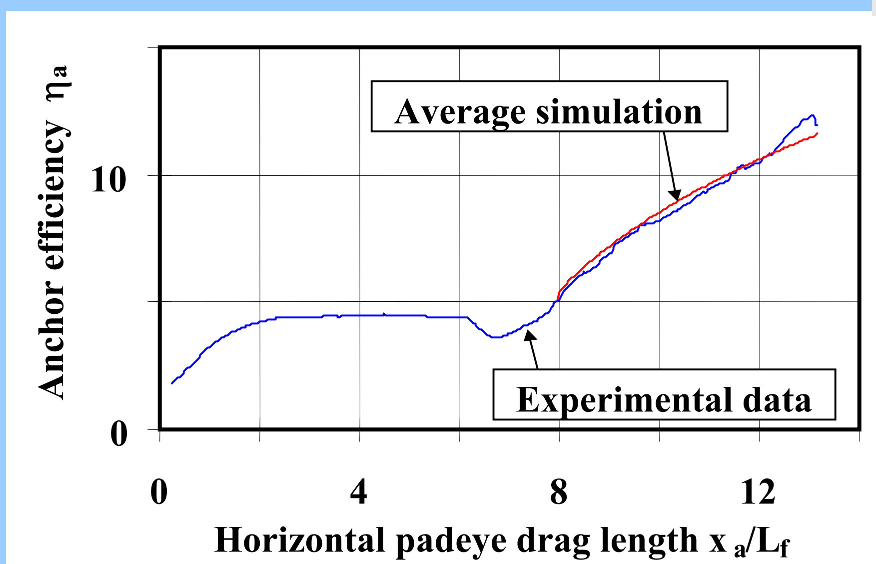
Drag anchor performance

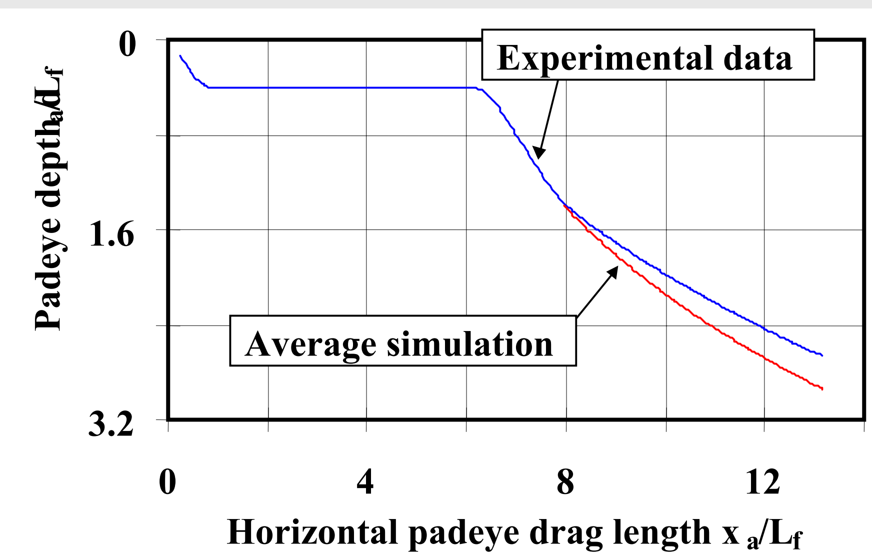


Drag anchor performance





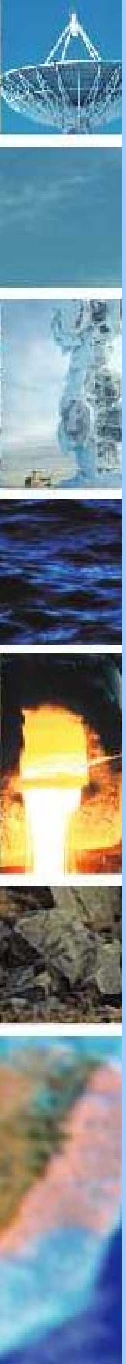




The Bold Possibilities of Centrifuge Modeling

When geotechnical design conditions are extreme or unfamiliar, and conventional analyses fall short, centrifuge physical modeling is the most reliable alternative to full scale trials. This can be used in engineering applications such as:

- **Foundation design for offshore structures rocked by ice flows**
- **Determination of depth of burial for submarine cables or pipes to prevent damage from ships running aground**
- **Assessing effects of explosives on above ground or buried structures**
- **Remedial engineering of an existing dam subject to earthquakes**
- **Planning the urgency of response to waste leaking from a pipeline into soil**
- **Determining freezing induced stresses on underground shelters, and frost jacking of foundations and pipelines**
- **Assessing risk of collapse into temporarily unsupported tunnels**
- **Designing site improvement by grouting or soil reinforcement**



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http://www.engr.mun.ca/~ccore/cgs/tc2/ and link to Cleopatre centrifuge ref dbase

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